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Modeling and Simulation of Wind Energy Conversion System Interconnected with Radial Distribution System

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***Abstract* – The global electrical energy consumption is steadily rising and consequently there is a demand to increase the power generation capacity. A significant percentage of the required capacity increase can be based on renewable energy sources.The integration of Distributed Generations into grid has a great importance in improving system reliability. The power generation with renewable energy sources is essential in now-a-days to control the atmospheric pollution and global warming. To get fast tracking for maximum power, it is preferable to use incremental conductance method. MPPT control for variable speed wind turbine is driven by Induction Generator. The wind turbine generator is operated such that the rotor speed varies according to wind speed to adjust the duty cycle of power inverter and maximizes wind energy conversion system efficiency. The system includes the wind turbine, induction generator, three phase rectifier, DC link voltage controller, three phase inverter. In this paper, modeling and simulation of wind energy conversion system (WECS) with incremental conductance maximum power point tracking (MPPT) is presented. This WECS is connected to electric utility to measure the performance. In this paper, the objective such as optimal location and sizing of DG units are studied to check the system performance in reducing the power losses, increase in voltage profile and reliability. For analyzing the performance of WECS, a case study is carried out on IEEE 15 bus radial distribution system. The case studies shows that there is gradual improvement in voltage profile, reduction in power losses and variation in reliability indices and results were simulated in the MATLAB/SIMULINK. The results shown in this paper can contribute well to electrical utilities with radial distribution systems.**

***Index Terms*-Distributed Generation, Incremental Conductance Algorit**hm, **Wind Energy Conversion System, Distribution System, Power Losses, Voltage Profile and Reliability.**

I. INTRODUCTION

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environment friendly. Renewable energies are becoming increasingly important as alternative energy sources. Wind power is one of the most-effective systems available today to generate electricity from renewable sources. This energy is transformed into mechanical energy by wind turbine and then converted to

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electrical energy by electrical generator and a power converter. To obtain maximum benefit from the wind energy, variable speed wind turbines are being used in general. Variable speed wind turbine systems produce variable voltage and frequency when no controller element is used. In order to extract maximum power in desirable values from variable speed wind generation systems, they must be operated together with the controller element [1]. The conventional back-to-back voltage source converter is usually used to connect the generator to the grid. The VSC can increase the system robustness and MPPT tracking control, many studies have been conducted to analyze, develop and improve the extraction of maximum power in literature [2-11].

The most common MPPT methods are Perturb & Observation (P & O) or Hill Climbing Method, Wind Speed Measurement (WSM), Power Signal Feedback (PSF), Incremental Conductance Method (INC). In the P & O method, the rotor speed is perturbed by a small step, then the power output is observed to adjust the next perturbation on the rotor speed. In [2, 3], a constant step is introduced in the perturbation process. A variable step is employed in [4] by considering the slope of power changes. In [5], an adaptive memory algorithm is added to increase the search operation. In [6], an advanced hill-climbing searching is proposed to work with different level of turbine inertia by detecting the inverter output power and inverter dc-link voltage.

In WSM method, the wind speed and rotor speed are measured and used to determine the optimum tip speed ratio (TSR). In [7], fuzzy logic control is employed to enhance the performance by dealing the parameter insensitivity. This method is simple, but has the drawbacks are it is difficult and expensive to obtain accurate value of wind speed, the TSR is dependent on the wind energy system characteristics. In [8], two (ANN) called ANN's wind estimation (ANN_{wind}) and ANN's power estimation (ANN_{pe}) are adopted to estimate the wind speed and output power respectively. The estimated wind obtained by ANN_{wind} not only replaces the anemometer but also solves the problems of aging anemometer and moved position.

The PSF method tracks the maximum power by reading the current power output to determine the control mechanism to follow the maximum power curve stored in lookup table. In [9], fuzzy logic control is developed to overcome the uncertainties of the power curves. The main drawback of this method is that the maximum power curve should be obtained by simulations or experimental test. Thus it is difficult and expensive to be implemented [10].

The P & O algorithm have some drawbacks. These would be overcome by the Incremental Conductance Algorithm (INC), which locate the maximum power point by comparing the incremental conductance with the instantaneous static conductance [11].

One of the simplest methods of running a wind generation system is to use an induction generator connected directly to the power grid, because induction generators are the most cost-effective and robust machines for energy conversion. However, induction generators require reactive power for magnetization, particularly during start-up, which can cause voltage collapse after a fault on the grid. To overcome such stability problems, the use of power electronics in wind turbines can be a useful option [12, 13].

Since wind speed varies unpredictable, it is convenient to develop the model to simulate the wind energy systems. The model usually consists of wind generation model, three phase rectifier, three phase inverter, load and controller (MPPT). In this paper, the system has been simulated with incremental conductance algorithm used as MPPT to track the maximum power of wind turbine. In the existing system [14] wind turbine with DC link has been used, but in the proposed system the MPPT with buck converter model and DG inverter controller has been added additionally in the wind generation system for better results.

The effectiveness of the proposed system is tested on IEEE 15 bus radial distribution system. The impacts will be evaluated by means of optimal location and sizing placing at different locations in a distribution system. Furthermore, the proposed analysis aimed at quantifying the distributed generation impact on total feeder losses, voltage profile and reliability. The results shown in this paper can contribute well to electrical utilities with radial distribution systems.

II. System Modeling

The proposed configuration of wind energy system is shown in Fig. 1. The wind generator consists of a wind turbine coupled with an induction generator. The rectifier is a three phase diode rectifier for converting three phase AC voltage to DC voltage. The voltage source convertor control is a DC-AC convertor, both Cuk and buck-boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage. It can also provide better output current characteristics due to the inductor on the output stage. Thus, the Cuk configuration is a proper convertor to be employed in designing the MPPT. In Fig.2 the

complete simulink model of wind Energy Conversion System is shown, based on Fig. 1. The description of the proposed wind energy system as shown in Fig. 2 is explained in the next section.

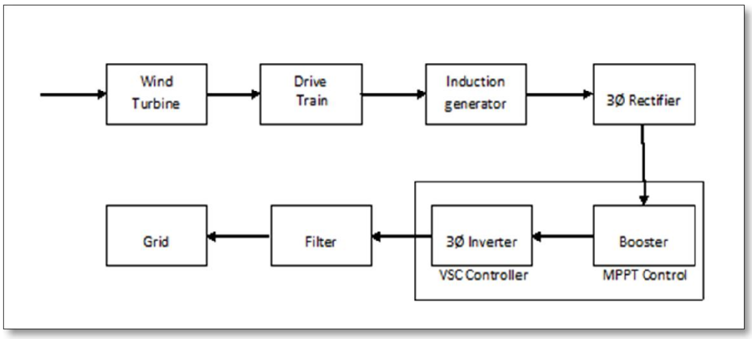

Fig. 1 The configuration of wind energy System

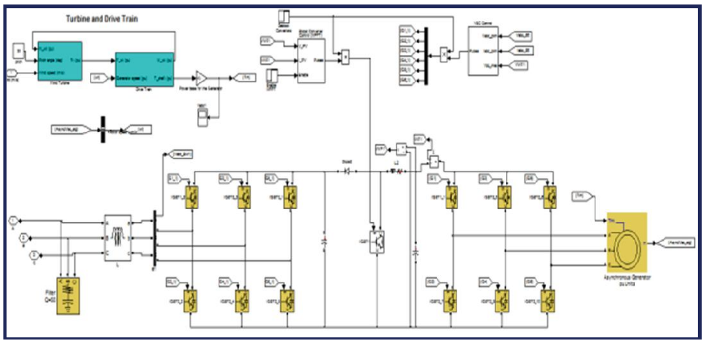

Fig. 2 Simulink model of wind energy conversion system

III. Wind Power Generation System

The wind power generation system is equipped with variable speed generator. Apart from the wind generator, wind power generation system consists of another three parts namely, wind speed, wind turbine and drive train.

A. Wind Turbine Model

The simulink model of the wind turbine is shown in Fig. 3. The simulation result of a wind speed as a function of time at an average wind speed of 11 m/s is shown in Fig. 4

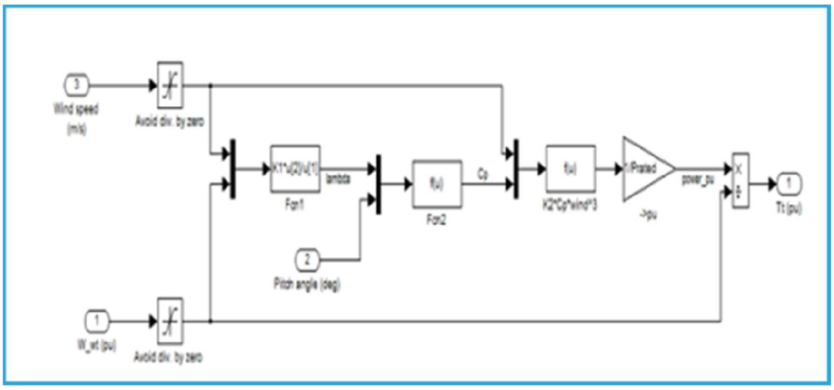

Fig. 3 Simulink model of wind turbine

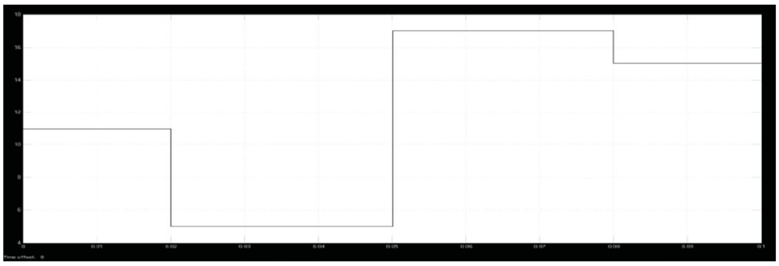

Fig. 4 Variation of wind speed

B. Drive Train Model

There are four types of drive train models usually available in power system analysis. To avoid the complexity in the system, commonly two mass model is considered and its simulink model is shown in Fig. 5.

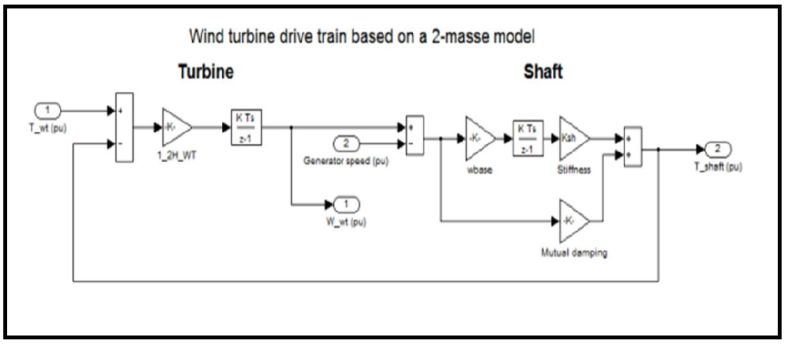

Fig. 5 Simulink model of drive train

C. Model of Generator associated with wind Generation

Both induction and synchronous generators can be used for wind turbine systems. Mainly, three types of induction generators are used in wind power conversion systems, they are cage rotor, wound rotor and slip control and double fed induction rotors. In this paper, wound rotor induction generator is chosen as it offers better performance due to higher efficiency and less maintenance. The simulink model of Induction Generator is shown in Fig. 6.

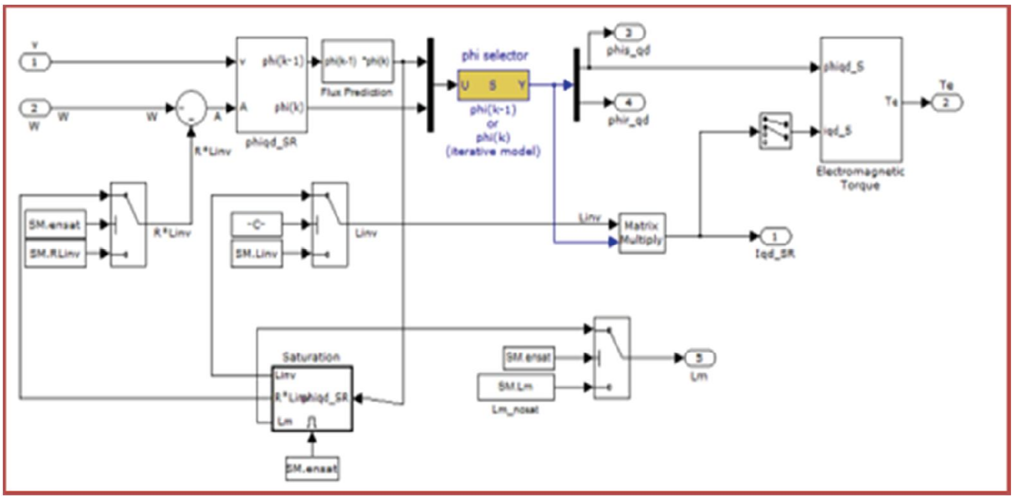

Fig. 6 Simulink model of wound rotor induction generator

IV. MAXIMUM POWER POINT TRACKING

A. *Incremental Conductance Method*

In this method the value of conductance is calculated and compared with the previous value and is taken as incremental conductance. If this value is equal to the negation of the present conductance value, then the duty

cycle is not varied. If this value is more than the negation of present conductance, then the duty cycle is increased, otherwise decreased.
To get fast tracking for maximum power, it is preferable to use incremental conductance method [15] with direct control which is based on the fact that maximum power occurs when the variation of dP/dV = 0. Since, the DC power across uncontrolled rectifier is governed by equation P = VI, from which the following equation

$$\frac{dP}{dV} = I + V\frac{\Delta I}{\Delta V}$$

The following constraints are used to calculate the MPPT using incremental conductance method

$$I + V\frac{\Delta I}{\Delta V} = 0 \text{ At } MPP \qquad (1)$$

$$I + V\frac{\Delta I}{\Delta V} > 0 \text{ Left to MPP} \qquad (2)$$

$$I + V\frac{\Delta I}{\Delta V} < 0 \text{ Right to MPP} \qquad (3)$$

“Equation (1) to (3)”, is used to determine the location of the operating point. Based on these equations the controller can easily take the decision of increasing or decreasing the operating voltage to reach power point. The simulink model of MPPT is shown in Fig. 7. The change in the duty cycle adjusted by the MPPT to extract the maximum power from the module is shown in Fig. 8. The waveforms of voltage, current and power for this change in duty cycles is shown in Fig. 9.

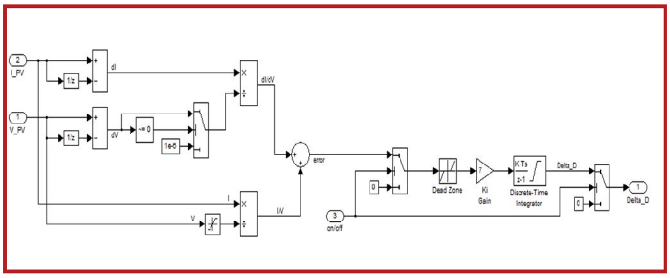

Fig. 7 Simulink model of MPPT control

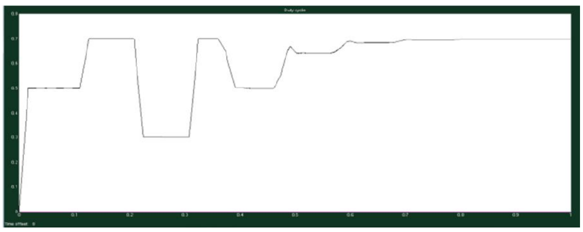

Fig. 8 Change in duty cycle of MPPT

C. *Proper Selection of Converter*

When proposing an MPP tracker, the major job is to choose and design a highly efficient converter, which is supposed to operate as the main part of the MPPT. Cuk and buck-boost converters provide the opportunity to have either higher or lower output voltage compared with the input voltage [15]. Some disadvantages such as

discontinuous input current, high peak currents in power components and poor transient response, make it less efficient in buck-boost. On the other hand, Cuk converter has low switching losses and the highest

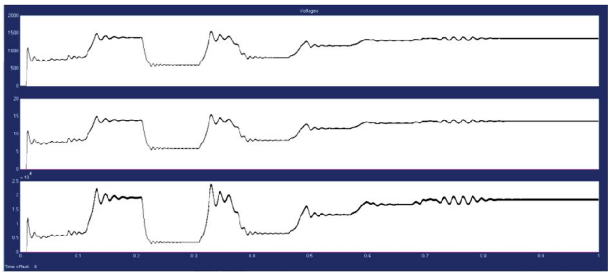

Fig. 9 Variation of voltage, current and power of INC MPPT

efficiency among non isolated dc-dc converters.
It can also provide better output-current characteristics due to the inductor on the output stage. Thus, the Cuk configuration is a proper converter to be employed in designing the MPPT.
The components for the cuk converter used in simulation were selected as follows:

1. Input inductor L_1 = 5mH
2. Capacitor C_1(IG Side) = 47µf
3. Switch : Insulated-gate bipolar transistor(IGBT)
4. Freewheeling diode
5. Capacitor C_2(Filter Side) = 1µf
6. Switching Frequency = 5KHZ

V. Distributed Generation Inverter Controller

For the control scheme, based on dq synchronous reference frame, the simulink model of inverter controller is developed and is shown in Fig. 10. In this system, the dc-link voltage controller and reactive power controller determine d and q components. The input power extracted from the DG units is fed into the dc-link. Therefore, the voltage controller counteracts the voltage variation by specifying an adequate value of the d-axis inverter current to balance the power flow of the dc-link [16].

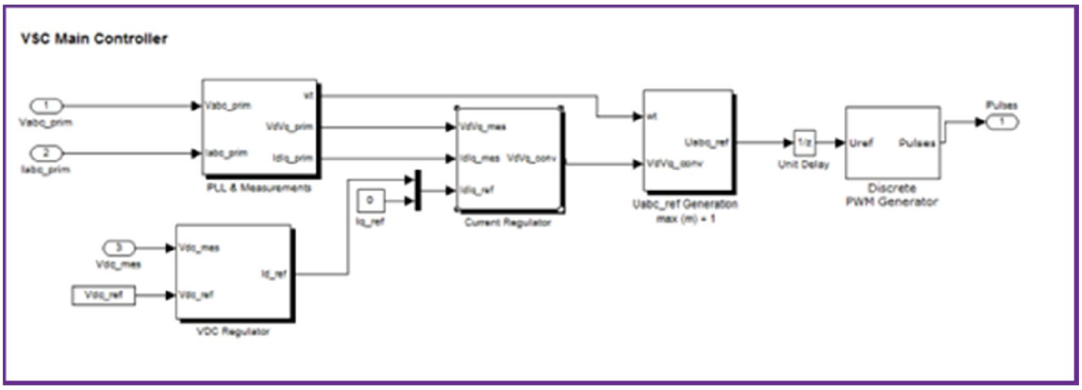

Fig. 10 Simulink model for voltage source inverter

VI. Distributed Generation Allocation

The placement of DG helps to reduce the power loss in the network. The optimum DG allocation can be treated as optimum active power compensation. It is observed that for a particular bus, as the size of DG is increased, the losses are reduced to a minimum value up to a certain size of DG which can be treated as optimal size of DG then the system losses are again increased above the minimum loss magnitude. Hence, the location and sizing of DG from loss reduction perspective has to be done carefully. The optimal size of DG varies from one bus to another bus. The best location can be chosen as the bus where the optimum DG

capacity injection gives the highest loss reduction. The determination of optimal DG capacity for every bus has to be done to arrive at the final decision on location and sizing of DG in the distribution network.

VII. Proposed Approach

In this paper, it is aimed at evaluating the integration of DG units to an IEEE 15 bus radial distribution system through measurable indices are

- ❖ The Active and Reactive Power Losses
- ❖ The voltage Profile at Generation Nodes
- ❖ The Customer and Load Energy Oriented Indices

The steps of the proposed approach are

1. Simulating the power system using MATLAB Software.
2. Measuring evaluation indices for the operating case before DG.
3. Selecting the DG best location and sizing at different loading levels according the measurable voltage index.
4. Check the effects of DG insertion.

VIII. DG Simulation Methods

The proposed methodology aims to evaluating the impact of location of DG units at various buses for reduction in power losses, improvement in reliability and voltage profile of distribution network. The single line diagram of the test system is shown in Fig.11.

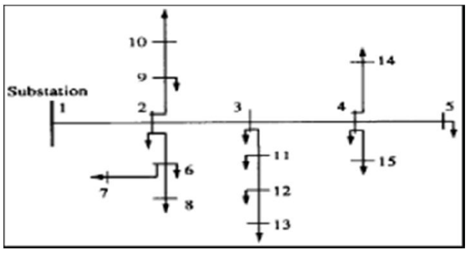

Fig. 11 Single line diagram of IEEE 15 bus system

A simulink model shown in Fig. 12 which is developed from the IEEE test system of 15 bus model is presented for the Fig. 11. The radial distribution system consists of 15 nodes. The flat voltage profile is 1.0 p.u. for the system at node 1. The range of the voltage is taken from 0.95 to 1.05 p.u. The average power factor of the feeder is 0.9. The repair time and switching time is 4 hrs and 0.1 hrs. The method is performed by inserting a DG unit which is aimed at achieving more benefits to the network, mainly in terms of reduced losses, improved voltage profile and reliability. In the related studied cases, the DG is modelled with Wind Turbine to efficiently consider the dynamic behaviour of the radial distribution system.

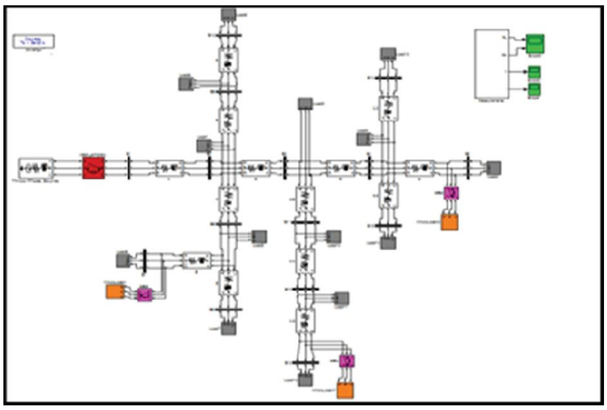

Fig. 12. Simulink model of 15 bus system with 3 DGs

IX. SIMULATION RESULTS

A. Voltage Profile

Power injections from DG can modify the usual direction of power flows in radial distribution networks and lead to voltage rise effect. The impact of voltage rise effect on the maximum DG capacity that can be connected to a distribution system shown in Fig.12 is illustrated. The DG locations and sizing are based on the voltage regulation. The voltages are analyzed at each and every node. The location of DGs is attained based on the corresponding lowest voltage values at the particular node point. The locations for a proposed system are 5, 7 and 13. The sizing is chosen of the range from 1 to 1.5MW based on the available capacity. The locations and its voltages after insertion of DG units and compared with base case are shown in Table 1. The variation of voltage levels before and after DG for all 15 buses is shown in Fig.13.

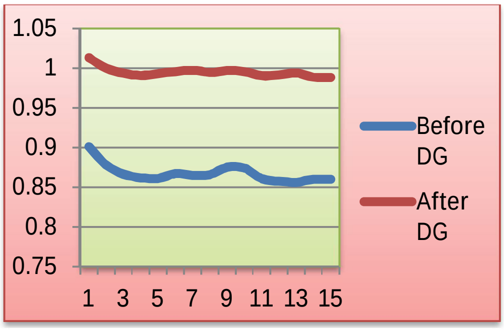

Fig. 13 Voltage variation before and after DG for 15 bus system

B. Power Losses

DG can normally, but not necessarily, reduces current flow in the feeders and hence contributes to power loss reduction. When DG is used to provide energy locally to the load, line loss can be reduced because of the decrease in current flow in some part of the network. However, DG may increase or reduce losses, depending on the location, capacity of DG and relative size of load quantity. The total power loss for the base case is 361.8 KW and after placing DG the total losses are reduced to 26.82 KW and the variation is shown with the help of bar chart in Fig. 14.

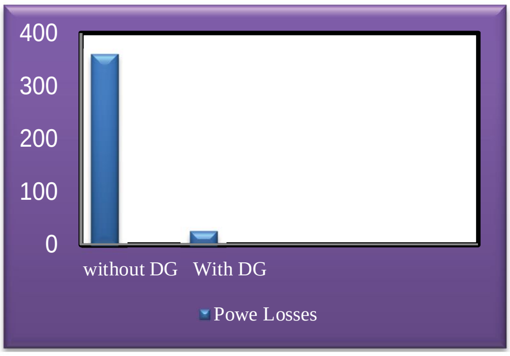

Fig. 14. Total power losses(kw) before and after DG

C. Reliability impact on DG Locations

The main purpose of integrating DG to distribution system is to increase the reliability of power supply. Reliability is one of the important characteristics of power system that consists of security and adequacy assessment. Both of them are affected by implementation of distributed generation in distribution system. The traditional reliability indices covered only sustained interruptions. The time necessary to start-up the DG should be taken into account for the reliability evaluation of the distribution system including DG. If this time is sufficiently short, the customers suffer a momentary interruption, while, if not, they suffer sustained interruptions. DG can be used as a back-up system or as a main supply in which the unit is operated in the case of local utility supply interruptions. The variation of customer oriented and load and energy oriented

indices are shown in Fig. 15. It can be seen that the duration related indices improves with DG installation, since some loads interruption duration reduces when the main supply is unavailable. Whereas the SAIFI remains constant in both the cases i.e., 5.4951. The system reliability indices after placing DG and compared with the base case are shown in Table 1.

TABLE I.CUSTOMER ORIENTED AND LOAD POINT INDICES

Indices	Before DG	After DG
SAIDI	21.9803	14.8367
CAIDI	4.0	2.7
AENS	115.2735	77.8096

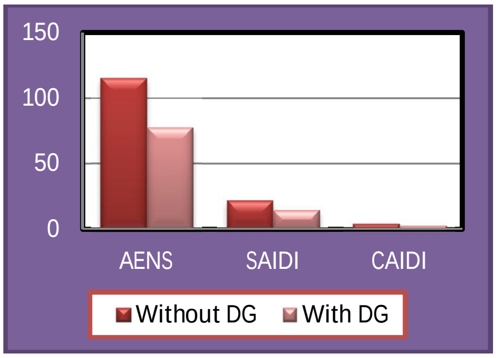

Fig. 15 Reliability improvement before and after DG

X. CONCLUSIONS

In this paper, Induction generator grid-connected wind energy conversion system, incorporating a MPPT for dynamic power control has been presented. Incremental conductance MPPT with direct control method is employed. The proposed system is simulated with a well-designed system including a proper convertor and selecting an efficient and proven algorithm. The modeling and simulation of the proposed system is developed by using MATLAB/SIMULINK.

To check the performance of the WECS it is integrated with radial distribution system. The DG effects on system power losses, voltage levels, reliability with DG location and sizing are illustrated, The selection of the best location and sizing that the DG unit must install is done based on voltage profile and is applied on IEEE test system and results are analyzed. The simulation results clearly indicate that DG can reduce the power losses, improve in voltage profile while simultaneously improving the reliability of the system.

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BIOGRAPHIES

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